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Published in:
Revista Latinoamericana de la Papa

Publication date:
2017

Document version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Hansen, G. L., Sørensen, M., Jacobsen, S-E., Ortuno, N., Angulo, A., & Terrazas, F. (2017). Organic production of native potato landrace "pintaboca" (Solanum stenotomum Juz. & Bukasov) in Bolivia: experimenting planting times and cultivation strategies. *Revista Latinoamericana de la Papa*, *21*(1), 22-38. http://ojs.papaslatinas.org/index.php/rev-alap/article/view/263

ARTÍCULO DE INVESTIGACIÓN

Revista Latinoamericana de la Papa 21 (1): 22 - 38 ISSN: 1853-4961
http://www.papaslatinas.org/revista.html

Organic production of native potato landrace "pintaboca" (*Solanum stenotomum* Juz. & Bukasov) in Bolivia: experimenting planting times and cultivation strategies

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Received: 02/10/2016

Accepted: 04/04/2017

Accessible on line: June 2017

Summary

In the municipality of Colomi, in the highlands of Bolivia, market pressure leads small scale farmers to substitute their native landraces with commercial potato varieties. Organic cultivation might offer a channel for selling native potatoes to an emerging industry of coloured native potato crisps. Nevertheless, as the area is endemic for late blight (*Phytophthora infestans*), adequate cultivation practices that allow organic production must be defined. The present experiment compared four cultivation strategies (two organic, which included the use of beneficial microoorganisms applied in the soil and through foliar spray, one conventional, which included cymoxanil and mancozeb based fungicides and a control with the same soil treatment as the organic strategies but no foliar spray) and two planting dates (early and main season planting) on a native potato landrace locally known as 'pintaboca' (*Solanum stenotomum*). Our results showed that early planting resulted in significantly higher yields, although the area under disease progress curve (AUDPC) of late blight did not differ significantly between planting dates. The lower yields in the plot planted during the main season were mainly due to the combined incidence of early and late blight. There was no significant difference in yields and quality of the tubers cultivated with conventional, organic or control treatment, with the exception that the largest tuber size category was produced only in the conventional treatment. We conclude that farmers in Colomi who want to shift to organic cultivation of the landrace 'pintaboca' at altitudes around 3,300 m a.s.l. could benefit from practicing early planting, although additional trials covering several seasons are needed to confirm our results.

Palabras clave adicionales: *Phytophthora infestans*, biofungicide, organic agriculture.

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Producción orgánica de papas nativas "pintaboca" (*Solanum stenotomum* Juz. & Bukasov) en Bolivia: experimentando tiempos de siembra y estrategias de cultivo

Resumen

En el municipio de Colomi, en las tierras altas de Bolivia, la presión del mercado lleva a los pequeños agricultores a sustituir sus cultivares nativos por cultivares comerciales de papa. El cultivo orgánico podría ofrecer un canal para la venta de papas nativas a una industria emergente de papas fritas de color. Sin embargo, como el área es endémica para el tizón tardío (*Phytophthora infestans*), deben definirse prácticas de cultivo adecuadas que permitan la producción orgánica. El presente experimento comparó cuatro estrategias de cultivo (dos orgánicas, que incluyeron el uso de microorganismos beneficiosos aplicados en el suelo y a través de pulverización foliar, uno convencional, que incluía fungicidas basados en cymoxanil y mancozeb y un control con el mismo tratamiento en el suelo que las estrategias orgánicas pero sin pulverización foliar) y dos fechas de siembra (siembra temprana y de temporada principal) en una papa nativa localmente conocida como 'pintaboca' (*Solanum stenotomum*). Nuestros resultados mostraron que la siembra temprana dio lugar a rendimientos significativamente más altos, aunque el área bajo curva de progreso de la enfermedad (AUDPC) del tizón tardío no difirió significativamente entre las fechas de siembra. Los rendimientos más bajos en la parcela plantada durante la temporada principal se debieron principalmente a la incidencia combinada de tizón temprano y tardío. No hubo diferencias significativas en los rendimientos y calidad de los tubérculos cultivados con el tratamiento convencional, orgánico o de control, con la excepción de que la categoría de tamaño de tubérculo más grande se produjo sólo en el tratamiento convencional. Llegamos a la conclusión de que los agricultores de Colomi que desean cambiar al cultivo orgánico del cultivar "pintaboca" a altitudes alrededor de 3,300 m.s.n.m. podrían beneficiarse de practicar la siembra temprana, aunque se necesitan ensayos adicionales que abarquen varias temporadas para confirmar nuestros resultados.

Palabras clave adicionales: *Phytophthora infestans*, biofungicida, agricultura orgánica.

Introduction

The area cultivated with potatoes in Bolivia accounts for 130,000 ha annually of which 26,000 ha are planted in the department of Cochabamba. This is the third largest department by order of cultivated area with this crop following the departments of La Paz and Oruro (Coca-Morante, 2012). The average yearly production of potatoes in the Department of Cochabamba in the period 2005–2007 was 136,632 tonnes (Zeballos *et al.*, 2009). The climate in the areas of highland agriculture in Bolivia is influenced by their distance from the transition zone between the Eastern Andean and the Amazonian regions. The Central Highland, being distant from the transition zone, is characterized by a dry climate, ideal for the cultivation of Andean seed crops such as quinoa (*Chenopodium quinoa* Willd.) and cañahua (*Chenopodium pallidicaule* Aellen). The municipality of Colomi (province Chapare, Cochabamba department) is situated in the centre-meridional part of the Eastern Andean mountain range, delimited by the subtropical region of the Yungas of Chapare to the North and the Cochabamba valleys to the South (Coca-Morante, 2012). It has a cold and humid climate ideal for the cultivation of Andean tubers. Colomi is a hotspot of agro-biodiversity with environmental, social and cultural characteristics that favour the conservation of Andean tubers' landraces. However, their production is exposed to risks, such as external market pressures, which lead to the replacement of native potato varieties with commercial ones (García *et al.*, 2003). Due to its climate, it is also an area with high incidence of *Phytophthora infestans* (Mont.) de Bary, the causal agent of potato late blight. This pathogen, which caused the Great Irish Famine in the middle of the 19th century, is the most severe potato disease worldwide (Henfling, 1987; Haverkort *et al.*, 2009). In cool and wet weather conditions, the swimming zoospores of this oomycete infect all plant organs. In optimal weather conditions with susceptible varieties, the disease can develop very quickly affecting entire fields, which results in severe yield losses (Henfling, 1987). Local farmers normally make effort to contain severe losses relying on the application of synthetic fungicides (Coca-Morante, 2012). This can have detrimental effects on the health of the small farmers, especially the less educated and poorest, as many highly and moderately hazardous pesticides are sold in the Andes, and they are applied and stored without proper safety measures (Orozco *et al.*, 2009; Cole *et al.*, 2011). Organic agriculture, intended as "farming systems where the use of pesticides, herbicides and chemical fertilizers is prohibited, […] which rely on crop rotations, natural nitrogen fixation, biologically active soil, recycled farm manure and crop residues, and biological or mechanical weed and pest control" (Bengtsson *et al.*, 2005), could offer a solution for reducing the exposure of local farmers and consumers to hazardous substances while preserving the quality of the soil and water through increased biodiversity (Altieri, 1999; Mäder *et al.*, 2002). Moreover, producing organically might open possibilities for the local farmers to improve their livelihoods by selling their crop with a price premium to national or international markets, for example to be transformed into organic coloured crisps (chips in U.S. English) and exported to specialized markets in Europe or the U.S.. An example of successful marketing of native potatoes has been documented by the Papa Andina Project and the T'ikapapa brand in Peru (Manrique *et al.*, 2011). Nevertheless, to achieve economically sustainable yields with organic farming, the risk of late blight needs to be reduced through the adoption of different cultivation practices. In particular, use of tolerant landraces, early planting and application of bio-fertilizers and bio-fungicides authorized in organic agriculture are practices normally used by organic growers. In Colomi the local native potato landrace 'pintaboca' (*Solanum stenotomum* Juz. & Bukasov) showed medium susceptibility to the pathogen *Phytophthora infestans* (Cadima *et al.*, 2004) and performed well when fried, therefore was chosen for this experiment.

The bio-fertilizers and bio-fungicides tested in this study produced by Biotop s.r.l., are based on the beneficial micro-organisms *Bacillus subtilis* (Ehrenberg) Cohn, *Bacillus amyloliquefaciens* (Fukumoto) Priest et al. and *Trichoderma* spp. which increase the nutrients uptake from the soil and the plant defence from pathogens through a mechanism of induced systemic resistance (Kloepper *et al.*, 2004; Ortuño *et al.*, 2010; Borriss, 2011; Chowdappa *et al.*, 2013). *Bacillus subtilis, Bacillus amyloliquefaciens* and *Trichoderma* spp. have been proven to effectively reduce the effects of *Helminthosporium solani* Durieu & Mont.

and *Phytopthora infestans* in potatoes (Kuepper and Sullivan, 2004; Stephan *et al.*, 2005; Mamani-Rojas *et al.*, 2012) and to increase tuber production (Franco *et al.*, 2011). Additionally, two species of Vesicular-arbuscular mycorrhizae (VAM) fungi (*Glomus fasciculatum* and *Glomus etunicatum)* were added to the soil in the organic treatments. The mycorrhizae produced by the association between the fungi and plant roots are known to enhance the absorption of plant mineral nutrients, especially phosphates, and contribute to soil aggregate formation (Sullia, 1991; Mäder *et al.*, 2002).

The objective of this study was to test whether early planting of native potatoes in August compared to the main seasonal planting in October is an effective method to reduce the severity of late blight and is therefore a recommendable practice for local organic cultivation. At the same time, conventional *vs*. organic cultivation strategies were tested for their yield and effectiveness in protecting the tubers against pathogens.

Materials & Methods

Study site

The experiment was carried out during the growing season August 2012/March 2013 in fields belonging to farmers in the district of Colomi, located 63 km East of the city of Cochabamba. Plot locations and soil characteristics at time of planting are indicated in Table 1. The first plot was planted on August 3rd 2012 and harvested on January 28th 2013 in the locality called Balcon-Sayt'o Loma. The plot was previously a 'puruma' soil, which means that it had not been cultivated for more than five years and was covered by the prevailing vegetation of the area: 'paja brava' or 'ichu' (*Stipa ichu* Kunth), 'th'ola' (*Baccharis* spp.), 'muña' (*Satureja parviflora* C.Presl) and the 'ch'ilka' (*Baccharis dracunculifolia* DC.) The second plot was planted on October 5th 2012 and harvested on March 6th 2013 in the locality Pico Central. The plot had been cultivated the previous year with oca (*Oxalis tuberosa* Molina) and ullucu (*Ullucus tuberosus* Caldas).

Table 1. Plot locations, planting and harvesting dates and soil characteristics at time of planting.

	Balcon-Sayt'o Loma (Early planting)	**Pico Central** (Normal planting)
Coordinates	S 17 12.310 W 65 57.975	S 17 19.369 W 65 56.620
Altitude	3,367 m.a.s.l	3,393 m.a.s.l.
Date planted	3/8/2012	5/10/2012
Date harvested	28/01/2013	6/3/2013
Soil characteristics		
Texture	Loam	Loam
% Clay	11	20
% Loam	46	46
% Sand	43	34
pH 1:2.5 (soil/water)	4.3	5.3
E.C. 1:2.5 (soil/water)	0.195	0.367
Interchangeable cations (me/100g) Potassium	0.87	1.31
Organic Matter %	15.29	8.36
Total nitrogen %	0.723	0.513
Available phosphorus (ppm)	0.9	20

Treatments

Field monitoring and treatments' applications were performed by a research assistant employed for the time of the experiment, while weeding and hilling were performed by the farmers who owned the plots. Two organic strategies (O_1 and O_2) included the use at planting time and 'in-season' of the following bio-fertilizers and bio-fungicides, according to the modality described in Table 2: 'Biobacillus'(*Bacillus subtilis* and *Bacillus amyloliquefaciens* 4 x 10^9 ufc/gr at 0,01% concentration), 'Mibac'(*Bacillus subtilis* 4 x 10^9 ufc/gr at 0.01% concentration, *Glomus fasciculatum* and *Glomus etunicatum* 30 spores/gr at 0,02% concentration) and 'Tricobal'(*Bacillus subtilis* and *Bacillus amyloliquefaciens* 4 x 10^9 ufc/gr at 0.01% concentration, *Trichoderma koningiopsis* and *Trichoderma hardzianum* 1 x 10^{12} spores/gr at 20% concentration), trademarks of BIOTOP s.r.l.;'Terra Biosa', produced by the company BIOSA®, which contains a mixture of various microorganisms, including *Lactobacillus* sp., *Bifidobacterium animalis*, *Streptococcus thermophiles*, *Leuconostoc pseudomesenteroides*, *Rhrodopseudomonas plustris*, *Saccharomyces cerevisise* and herb extracts diluted in water and sugar molasses; 'Timorex Gold®' by Stockton Group, produced by BIOMOR Israel, which contains tea tree (*Melaleuca alternifolia*) oil at 22.25 %.

Table 2. Scheme of the treatments applied at sowing time and on the foliage in each of the strategies.

Strategy	**Products applied to the soil at sowing time**	**Weekly foliar sprays starting from week 11 after sowing**
$O_{1,\ Organic\ 1}$	Tricobal (2 kg/ha)+ Mibac (20 kg/ha)+Organic manure (10.7 t/ha)	Biobacillus (2 kg/ha) and Terra Biosa® (2 L/ha) at alternate weeks
$O_{2,\ Organic\ 2}$	Tricobal (2kg/ha)+ Mibac (20 kg/ha)+Organic manure (10.7 t/ha)	Timorex (2 litres/ha) and Terrabiosa (2 L/ha) at alternate weeks
$T_{0,\ Control}$	Tricobal (2 kg/ha)+ Mibac (20 kg/ha)+Organic manure (10.7 t/ha)	No treatment
$T_{c,\ Conventional}$	Chicken manure (15.7 t/ha)	Bordeaux mixture at week 13, Curathane 50% + Dithane 50% weeks 14 and 15, Coraza weeks 16 and 17

Tricobal was diluted in water and applied on the seed potatoes before planting, while Mibac was applied in dry form on top of manure at sowing time. The other products were applied with a backpack sprayer during the growing season, as indicated in Table 2. The conventional strategy normally used by the farmers of the area (Tc) included the applications of chicken manure at planting time and treatments on the foliage made with: Bordeaux Mixture made with a copper sulfate base and calcium oxide solution in a 1 to 9 ratio, as indicated by Donaire-Eguívar & Garcia (2006); Curathane ®72WP (7 gr/L), cymoxanil 8% + mancozeb 64%, Dithane® M-45 (10,5 gr/l), mancozeb 75% MP by DOW Agroscience; Coraza (4.5 g/L), cymoxanil + mancozeb by Serfi S.A. The products were applied by backpack sprayer. The control (T_0) consisted in the same treatment at planting time as O_1 and O_2, but no treatment ‘in-season’ on the foliage (see Table 2). We used this treatment as a control to verify whether there had been any effect by the foliar sprays applied during the growth season to the organic treatments.

Experimental design

The design of the experiment consisted in a randomized block with four treatments (O_1, O_2, T_0 and T_c) and four blocks. This set up was repeated in two separate plots owned by farmers at the same approximate altitude of 3,380 m.a.s.l., at different planting times. The comparison was possible using the model series of experiments where the lots were the localities and the blocks within each locality were evaluated as nested effect since the blocks vary from locality to locality. The model was: Performance = Locality + Block (Locality) + Strategy + Locality * Strategy + error. Each experimental unit consisted of 5 rows at 0.70 m distance between rows. In each row of 5 m, opened by hand-hoe, 17 tubers were planted at 0.30 m of distance and the three central rows were harvested for yield assessment (excluding the first and last plant, i.e. borders). The native potato locally known as ‘Pintaboca’ (a landrace of *Solanum stenotomum*) was chosen because of its medium susceptibility to late blight infection as well as for its attractive colour and adaptability to be transformed in potato crisps, which makes it a marketable landrace.

Weekly monitoring

The early planted plot (Balcon) was monitored every week starting from week 11 after planting until week 23, while the plot planted at normal time (Pico Central) was monitored from week 8 until week 22. The observed parameters were: percentage of emergence, height of plants, incidence and severity of late blight (*Phytophthora infestans*), early blight (*Alternaria solani*). To determine the severity of the late blight on the foliage we used the international scale from 1 to 9 (1=0% no lesion observed and 9= 100% all the leaflets and stems wilted) mentioned by Gabriel *et al.* (2010).

The weekly severity measurements of affected foliage were then used to calculate the Area Under Disease Progress Curve (AUDPC) of late blight and early blight, which is a quantitative summary of disease intensity over time (Madden *et al.*, 2007).

Harvest

The early planted field was harvested on 28th January 2013, i.e. 178 days after planting (DAP) and the normally planted field on the 6th of March 2013, i.e. 152 DAP. The potato tubers of the various treatments were separated, and divided by size and weight into the locally known categories: Chapara, Qolque, Machu Murmu, C'hili murmu and C'hili (Table 3).

Table 3. Local categories of potato size in the indigenous Quechua language. Average weight, length and diameter were calculated from samples of the potatoes harvested in our experiment.

Local name	Average weight	Average length	Average diameter
	g/tuber	cm/tuber	cm/tuber
Chapara	136.6	14.3	4.0
Qolque	95.0	11.3	4.0
Machu murmu	56.6	7.0	3.1
C'hilimurmu	35.0	5.2	3.0
C'hili	20.0	3.8	2.0

Participatory Evaluation

On the harvest day of the early planted plot, the family who had provided the land plus four other farmers performed an evaluation of the yield of the four strategies. The harvested potatoes, divided according to strategy and size categories, were placed in front of four signs listing the products that had been used at planting time and through the growing season, with the respective total cost. This was calculated by multiplying the price per litre or per kilogram of the products utilized per the quantity utilized in each treatment (four plots of 17.5 m^2). No other costs (e.g. men labour) were considered. Then the farmers were asked to rank the four treatments on a scale from 1 to 4, where 1 was the best and 4 the poorest, according to their preference considering quantity and quality of the tubers and price. The cost of the treatments was the following (cost of treatment of four plots of 17.5 m^2 each): Strategy O_1 = 122 BOB, Strategy O_2= 120 BOB, T_c= 120 BOB, T_0= 110 BOB. (BOB = Bolivian Boliviano, the local currency, corresponding to 0.14 USD)

Tubers evaluation

A sample of 10 tubers from each experimental unit (EU) (16 EU, 160 tubers) was analyzed for incidence and severity of the diseases: late blight (*Phytophthora infestans*), black scurf (*Rhizoctonia solani*) and silver scurf (*Helminthosporium solani*), being these common diseases affecting potato tubers in the area (of these, only *Phytophthora infestans* was among the diseases evaluated on the aerial parts). The scale used for black scurf ranged from 1 to 6 as reported in Gabriel *et al*. (2010), the scale for silver scurf ranged from 0 to 4 adapted from the evaluation scale used for *Streptomyces scabies* in Gabriel *et al*. (2010) and the scale for *Phytophthora infestans* ranged from 0 to 10.

Results

Potato yield in the study sites was influenced by the planting time. Our data showed a highly significant difference ($p<0.01$) between the yields of the plot planted in August (average 16.78 t/ha) and the yields of the plots planted in October (average 1.97 t/ha) (Figure 1).

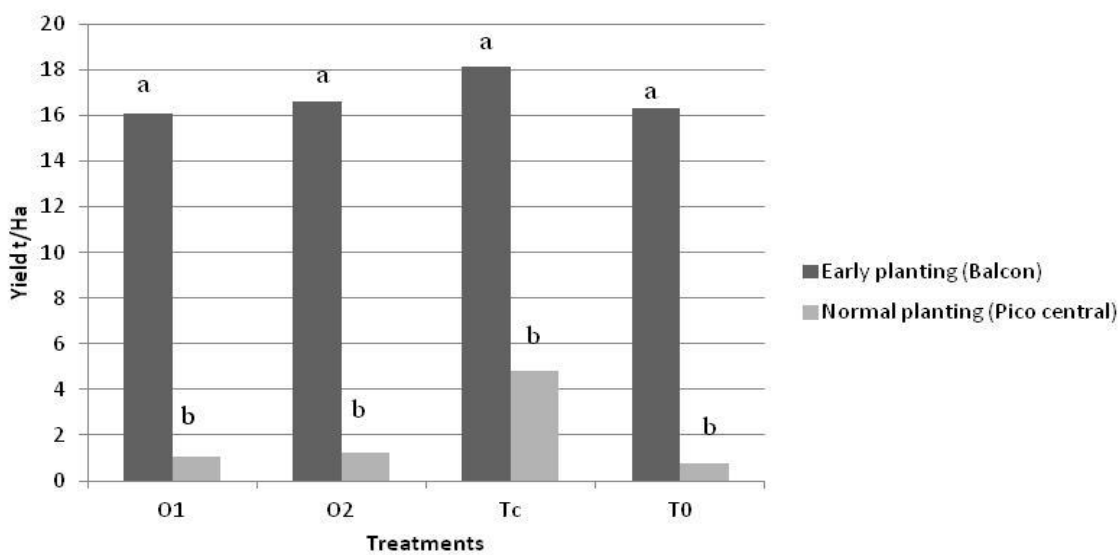

Figure 1. Average yield of conventional (T_c) and organic (O_1, O_2) cultivation systems (T_0 =control) applied in two different planting seasons. The early planting was done on the 3rd August 2012 while the normal planting was done on the 5th October 2012.

The yield variation was highly significant for all the potato size categories (Table 7). Of the 45 plants that should have been harvested in each experimental unit (17 tubers × 3 central rows minus the first and last plant in each row) the mortality rate was very different between early planting and normal planting as shown in Table 4. In the plot planted in August, the average mortality rate was 6.11 %, with no significant difference between the four strategies. In the plot planted in October the average mortality rate was 63.88% and there was a significant difference between strategies, where the conventional one T_c reported the lowest mortality, while the organic strategy O_2 the highest, due to the major incidence of early blight in this strategy.

Table 4. Mortality rates in the early planted and in normal planted plots. The rate was calculated as a percentage of the 45 plants that should have been harvested in each experimental unit at harvest time.

Strategy	Early planting		Normal planting	
n=45				
Organic 1	7.78	a	66.67	ab
T0, Control	6.67	a	70.00	ab
Tc, Conventional	6.11	a	40.00	b
Organic 2	3.89	a	78.89	a

Means with the same letter are statistically equal (p<0.05)

The cultivation strategies (T_c, O_1, O_2 and T_0) alone could not explain the yield variation, with the exception of the tubers of the biggest size 'chapara', which only grew in the T_c plots (Tables 5, 6).

Table 5. Yields (t/ha) divided according to local size categories of four conventional and organic systems under early planting conditions.

Strategy	Total yield	Chapara	Qolque	Machu murmu	Ch'ili murmu	Ch'ili
			(t/ha)			
O1	6.057 a	0 b	5.709 a	5.235 a	4.118 a	0.871 a
O2	6.629 a	0 b	6.762 a	4.714 a	3.819 ab	1.209 a
T0	6.338 a	0 b	6.577 a	5.097 a	3.370 ab	1.264 a
Tc	8.105 a	4.365 a	5.767 a	4.617 a	2.342 b	0.781 a

Means with the same letter are statistically equal (p<0.01)

Table 6. Yields (t/ha) divided according to local size categories of four conventional and organic systems under main planting conditions.

Strategy	Total yield	Chapara	Qolque	Machu murmu	Ch'ili murmu	Ch'ili
			(t/ha)			
O1	1.049 a	0 a	0.024 a	0.271 ab	0.182 b	0.460 b
O2	1.259 a	0 a	0.124 a	0.266 ab	0.275 b	0.398 b
T0	0.762 a	0 a	0.043 a	0.097 b	0.212 b	0.395 b
Tc	4.818 a	0.116 a	0.602 a	1.107 a	0.936 a	1.461 a

Means with the same letter are statistically equal (p<0.01)

Our results show no significant difference in AUDPC of late blight caused by *Phytophthora infestans* for the two planting dates. In the plot planted in August (early planting) late blight was first recorded on the 7th November 2012 (100 days after planting) and reached 75% (as average of all treatments) around 150 DAP. In comparison, the plot planted in October (main planting season) was first infected by early blight caused by *Alternaria solani* and then by late blight caused by *Phytophthora infestans*. Early blight was first recorded on 13th December 2012 (69 DAP) and the disease reached 75% severity around 123 DAP. Late blight was first recorded on 24th January 2013 (111 DAP) and reached 20.42% infection 147 DAP. At this point the plot was already heavily damaged by early blight, and the effects of the two diseases caused the very high mortality rate shown in Table 4. According to the measurements in the metereologic station of Colomi, the plot planted in August received in total 243 mm of rain, while the plot planted in October received 303 mm of rain (Senamhi, 2013). The month with the highest number of rainy days (15) was December with a total of 93.7 mm of rain, where the heaviest rainfalls happened on the 4th, 8th, 17th and 19th of the month. The years 2012 and 2013 recorded a total amount of rain of 572 and 444.4 mm respectively, where the average for the area based on data from 1977 to 2015 is 602.3 mm with a standard deviation of 124.69 mm. So the values for 2012, which included the month with highest rainfall, are within the normality. In the early planted plot there was a highly significant ($p<0.01$) relation between strategies and AUDPC of *Phytophthora infestans*. The AUDPC in the Tc strategy was significantly lower than that of the other strategies. On the contrary, there was no significant relation between strategies and AUDPC of *Phytophthora infestans* in the main planting season (Table 8).

Table 7. Comparison of total yield of each potato size cathegory between early and main planting.

Planting date	Total yield	Chapara	Qolque	Machu murmu	C'hili murmu	Ch'ili
			(t/ha)			
Early planting	16.78 a	0.609 a	6.19 a	4.91 a	3.376 a	1.03 a
Main planting	1.97 b	0.028 b	0.18 b	0.39 b	0.358 b	0.68 b

Means with the same letter are statistically equal ($p<0.01$)

Table 8. Area under disease progress curve (AUDPC) for late blight (*Phytophthora infestans*) on the potato landrace "pintaboca', assessed under four control strategies in early planting and main planting season. The comparison was performed between control strategies in each planting season.

	AUDPC late blight	
Strategy	Early planting	Main planting
O1	42.46 b	48.32 a
O2	42.75 b	46.67 a
T0	42.70 b	38.95 a
Tc	13.58 a	33.09 a

Means with the same letter are statistically equal ($p<0.01$)

Regarding the AUDPC of early blight (caused by *Alternaria solani*), which affected only the main season planted plot (Pico central) from week 11, there was a significant ($p<0.05$) difference between the AUDPC of *Alternaria solani* in the conventional strategy T_c and the organic strategy O_2 (Table 9). The conventional strategy reduced the AUDPC compared to the organic strategy O_2 by almost 60%. The tubers harvested in the main season planted plot presented a significantly higher severity of infection of silver scurf (*Helminthosporium solani*) (Table 10). In contrast, there was no relation between planting date and severity on tubers for rhizoctonia blight (*Rhizoctonia solani*). In both plots the harvested tubers did not present any sign of late blight (*Phytophthora infestans*) infection. There was no significant relation between the different treatments T_c, O_1, O_2 and T_0 and severity of tuber infection by black scurf (*Rhizoctonia solani*) and silver scurf (*Helminthosporium solani*).

Table 9. Area under disease progress curve (AUDPC) for early blight (*Alternaria solani*) on the potato landrace "pintaboca', assessed under four control strategies in the main planting season.

	AUDPC early blight
Strategy	**Main planting**
O1	55.95 ab
O2	61.24 b
T0	55.55 ab
Tc	28.51 a

Means with the same letter are statistically equal ($p<0.01$)

Table 10. Severity of tuber damage caused by black scurf and silver scurf under four cultivation strategies in two planting dates.

Planting time	**Strategy**	**Silver scurf**	**Black scurf**
Early	O1	0.568 a	2.300 a
Early	O2	0.589 a	3.225 a
Early	T0	0.500 a	2.500 a
Early	Tc	0.762 a	2.325 a
Main season	O1	3.316 b	2.800 a
Main season	O2	3.516 b	2.525 a
Main season	T0	3.197 b	2.250 a
Main season	Tc	2.367 b	1.825 a

Means with the same letter are statistically equal ($p<0.01$)

Revista Latinoamericana de la Papa 21 (1): 22 - 38 ISSN: 1853-4961
http://www.papaslatinas.org/revista.html

Participatory evaluation of the harvest

The strategy preferred by the farmers was T_0, as it required less input of products and work while providing comparable yields to the organic strategies. This was followed by the organic treatment O_2, the organic treatment O_1 and finally the conventional treatment T_c . Statistically there is a highly significant preference for T_0 against the other strategies, while there is not a significant difference between the strategies O_1, O_2 and T_c (Table 11). Among the reasons stated by the farmers for their preference for the control T_0 were: “it's healthy”, “the potatoes do not have diseases”, “there is no waste of money”, “it has produced without use of chemicals”. Reasons for ranking O_2 at the second place: “it produces bigger and more than O_1”, “because it uses cattle manure instead of chicken manure”, “it required more products, but it is affected by pests more than T_0”. Reasons for ranking O_1 at the third place: “it costs more than the O_2”. Reasons for ranking T_c at the fourth place: “because chemicals damage the environment”, “because chemicals affect our health and nature”, “it is more poisoned”.

Table 11. Means of farmers' degree of preference of the four strategies.

Strategy	Average rank
O1	2.8 a
O2	2.4 a
T0	1.0 b
Tc	3.8 a

Means with the same letter are statistically equal ($p<0.01$)

Economic considerations

Considering the average market price in Colomi and Cochabamba for each potato size category in 2013 (Table 12), the total profit for each strategy was calculated for the harvest of the early planted plot (Table 13). The profit would be 25339.2 BOB ha^{-1} for the organic strategy O_1, 28141.4 BOB ha^{-1} for the organic strategy O_2, 28884.0 BOB ha^{-1}for the control treatment T_0 and 43177.6 BOB ha^{-1} for the conventional strategy T_c. The conventional strategy has a higher yield per hectare and is the only strategy that produces the potatoes of size “chapara”, which have the highest price on the market. Therefore, in order for organic strategies O_1 and O_2 and the control treatment T_0 to provide the same profit per hectare as the conventional treatment, a price increase or “organic bonus” of 42%, 33% and 32% respectively would be necessary.

Table 12. Prices for 100 kg of potatoes by size cathegory*.

Chapara	Colque	Machu Murmu	Ch'ili Murmu	Ch'ili
		(BOB/100kg)		
5250	3500	2250	2250	2000

* average between the price in the market in Colomi and Cochabamba in 2013

Table 13. Potential revenue per hectare for each strategy of the early planted plot according to 2013 local market prices and the percentage price increase necessary for organic potatoes to obtain the same profit per hectare as the conventional treatment tested.

	Chapara	Qolque	Machu Murmu	C'hili Murmu	Ch'ili	Revenue / ha	Cost/ha	Profit	Organic price increase
				(BOB/ha)					
O1	0.0	19981.5	11778.8	9265.5	1742.0	42767.8	17428.6	25339.2	42 %
O2	0.0	23667.0	10606.5	8592.8	2418.0	45284.3	17142.9	28141.4	33 %
T0	0.0	23019.5	11468.3	7582.5	2528.0	44598.3	15714.3	28884.0	32 %
Tc	22916.3	20184.5	10388.3	5269.5	1562.0	60320.5	17142.9	43177.6	0

Discussion

Planting earlier resulted in significantly higher yields. The Area Under Disease Progress Curve (AUDPC) of *Phytophthora infestans*, which is a summary of disease severity, did not significantly differ between planting dates, but the plot planted in the main season, i.e. the traditional practise, was additionally infected by early blight *Alternaria solani*.

So, the early planting *per se* did not decrease the severity of late blight, but shifted the bulking phase of the potatoes to an earlier point, allowing the plants to produce tubers for a longer time before the infection of *Phytophthora infestans* and *Alternaria solani* stopped further tuberization. In fact, according to Large (1952) mentioned in Chaube and Pundhir (2005), "Studies on mean bulking curves (MBC) revealed that further tuberization stops once 75% of the foliage has been damaged. However, for certain other cultivars this value was reported to be 40–50%". Tuberization in the landrace 'pintaboca' (*Solanum stenotomum*) starts approx. 78 DAP, simultaneously with the appearance of the first flowers, and the potato plants in the area have a life cycle of 155–166 days (Patiño *et al.*, 2003). In the early planted plot late blight was first recorded 100 days after planting and reached 75% severity around 150 days after planting. In the plot planted in October, early blight was first recorded 69 days after planting and the disease reached 75% severity around 123 days after planting. The late planted plot had a considerable shorter healthy period of tuberization, which explains the minor yields obtained.

Variation in yield between different planting times might also have been influenced by the quality and the previous use of the soil as the experiments were carried out at two different locations (Balcon and Pico Central). The soil in

Balcon had a higher sand content and higher organic matter and nitrogen content (Table 1). Moreover, the early planted plot in Balcon had previously been left fallow for more than 5 years, while the plot in Pico Central was cultivated with the tuber crops oca (*Oxalis tuberosa*) and papalisa (*Ullucus tuberosus*) the year before.

During the growth period of the plot in Pico Central (main season planting) it was noted that plants from the residual tubers of oca and papalisa from the previous season were growing in the rows of the experiment and they had to be removed regularly as weeds. The competition for nutrients with these 'residual' plants might have led to a negative effect on the growth of our potato crop.

It would have been ideal to carry out the experiment at only one location, but working under field conditions we had to adapt to the availability of land provided by the farmers. This is of course not ideal and future experiments are recommended to be carried out at one site only and for consecutive years, to establish more accurately the influence of planting time on yields.

A significant effect of the strategies adopted (O_1, O_2, T_0, and T_c) for plant protection (in terms of AUDPC of *Phytophthora infestans*) was noted only in the early planted plot and even in this case only the T_c differed significantly from the control T_0. Hence, the alternate use of Biobacillus and Terrabiosa and of Timorex and Terrabiosa did not prove to have any effect on the plants and therefore cannot be suggested as valid anti-fungicides to the farmers with the dosage tested.

Our results in the early-planted experiment, reported no significant total yield difference between the organic, the conventional and the control strategies. The only difference between strategies was that tubers of the largest size 'Chapara', i.e. on average 14.5 cm long, were produced by the plants cultivated under conventional Tc treatments only. If the potatoes had to be used to produce organic potato crisps, the industry should be adverted that the largest size category obtainable according to our experiment would be the 'Machu murmu'. Instead the smallest sizes of organic potatoes could be sold to high-end restaurants, which require the smallest sized categories, sold as 'gourmet potatoes' (Hugo Bosque, pers. comm.). Also in the main season planted experiment there was not a significant difference between the yields of conventional and organic agriculture (Table 6). Although, in this case, the plants were highly affected first by the attack of *Alternaria solani* and then by *Phytophthora infestans* and none of the strategies gave satisfactory yields.

Local farmers who participated in the evaluation of the harvest, seeing no considerable difference between the results of the conventional, organic and the control plots, stated that they would not apply any of the tested organic products to be used as foliar spray the following year. Instead, they were interested in using the T_0 strategy because, according to them, this would save time, money and effort while producing similar yields to the organic strategies O_1 and O_2, while being more healthy than the conventional. The T_0 strategy was also the one that would need the least price increase (32%) in order to produce the same profit per hectare as the conventional. Economic profitability of the organic treatments might be increased with improved nutrient management. In an experiment with the potato landrace "waycha", the application of the organic foliar spray Fertisol (produced by PROINPA) with a frequency of three times during the growing season, increased the production of the tubers of the largest size Chapara by 33% (Mamani *et al.*, 2016). It would be interesting to test the production and the relative economic viability with the introduction of this product, as under the current treatments no size 'Chapara' was produced in the organic strategies, while this is the most valuable category on the market.

Conclusion

From the results of this study we recommend early planting as a management strategy for organic cultivation of the landrace 'pintaboca' in Colomi at average altitudes of 3,330 m.a.s.l. Nevertheless, further studies are necessary to repeat the experiment of planting in August against planting in October with plots in the same location.

In order to test the effectiveness of the products Tricobal and Mibac that here were applied simultaneously at planting, another experiment should be made testing each product separately and with higher concentrations against a control with no application. The same setup should be conducted for the bio-fungicides applied on the foliage.

Conflict of interests

The authors declare there is no conflict of interest in the publication of the results of this research.

Acknowledgements

We are most grateful to the farmers Casto Carballo and Hugo Porrez and their families, who provided the land and part of the labor for the experiment. Thanks to the colleagues from PROINPA Cochabamba, especially Gonzalo Tiñini Huanca, Rhimer Gonzales and Mayra Claros for support in the field and laboratory. The study was financed by the University of Copenhagen through the grant conceded to the Ph.D. Candidate Gaia Luziatelli.

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